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INCREASING CRUDE PROTEIN CONTENT OF FORAGE WITH ATRAZINE ON SHORTGRASS RANGE

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SUMMARY

Atrazine, applied annually, increased crude protein content of shortgrass range herbage each year for 3 years, 1969–71. With application in December, 3 pounds per acre of atrazine increased average crude protein content of herbage 53 percent, and when applied with 40 pounds of nitrogen per acre, the combined effect increased average crude protein 76 percent. One pound per acre of atrazine increased both average protein content and herbage yields only slightly when applied in either December or in May. Three pounds per acre of atrazine applied both in December and in May reduced herbage yields in June 1971 after a series of early spring storms. When applied in July in combination with 40 pounds per acre of nitrogen, both the 1 pound and 3 pounds per acre rates of trazine reduced average herbage yields.

When applied in December or in May, the most effective treatments for increasing average protein yield without depressing herbage yield were a combination of 1 pound of atrazine and 40 pounds of N (increase of 148 percent and 126 percent, respectively). When applied in June, the combination of 3 pounds of atrazine and 40 pounds of N was the most effective (increase of 131 percent), and when applied in July, 40 pounds of N alone was most effective (74 percent increase).

Foliar applications of ammonium nitrate repeated annually during midsummer substantially increased nitrate-N content of herbage in the third year, though not to toxic levels.

Atrazine controlled most annual forb and grass species. This tended to improve species composition for forage.

INTRODUCTION

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) is well known for its herbicidal action on annual grasses and forbs. It also increases crude protein concentration in many plants and may increase yields. Increased crude protein on rangelands can be important for livestock production. Crude protein levels in range forage are often low—even below required nutrient levels—for 8 or 9 months of the year. We have no great need on rangelands for the herbicidal action of atrazine, but increased protein may provide significant advantages in livestock production. In addition to being an essential nutrient, crude protein is also generally associated with the important forage characteristics of palatability and digestibility (*14*).[2]

Furtick (*4*) was among the first to show that crude protein concentration and growth of plants may be increased by applications of low rates of several herbidicides. Fink and Fletchall (*3*) and Pulver and Tweedy (*9*) found that atrazine decreased top growth but increased crude protein and nitrate nitrogen (N) concentrations in corn

[1] Cooperative investigations of Agricultural Research Service, U.S. Department of Agriculture, and Colorado State University Experiment Station, Colorado State University Experiment Station Scientific Series Paper No. 1776. The authors express their appreciation to Geigy Chemical Corporation for materials used in this study.

[2] Italic numbers in parentheses refer to Literature Cited, p. 10.

(*Zea mays* L.), particularly at low levels of applied N fertilizer or in the absence of additional N. Similar results have been found by Ries and Gast (*10*), and Ries, Schweizer, and Chmiel (*11*) for corn as well as other crops. Kay (*8*) found increases in both yield and protein content in range forage from applications of atrazine. Doroshenko and Yatsyuk (*2*) showed increased crude protein in lupine (*Lupinus luteus* L.) seed from applications of atrazine.

The mechanism by which the triazine compounds influence plant protein, nitrate-N, and yield is not well understood. However, Tweedy and Ries (*13*) found increased nitrate reductase activity in corn treated with simazine (2-chloro-4,6-bis [ethylamino-6-isopropylamino]-s-triazine), suggesting more rapid assimilation of N. They indicated that the increased activity of nitrate reductase from simazine applications was demonstrable only under suboptimal growing conditions.

The objective of the research reported here was to study the effects of low rates of atrazine with and without N fertilizer on crude protein content and yield of semiarid shortgrass range and species composition by frequency (*6*).

EXPERIMENTAL AREA AND METHODS

The study area was located at the Central Plains Experimental Range about 40 miles northeast of Fort Collins, Colo. The soil was classified as Ascalon sandy loam. The native vegetation is typical of the shortgrass plains.

Cover was dominated by blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.). Other abundant species were sun sedge (*Carex heliophylla* Mack.), plains pricklypear (*Opuntia polyacantha* Haw.), scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.), wooly indianwheat (*Plantago purshii* Roem. and Schult.), and six-weeks fescue (*Vulpia octoflora* (Walt.) Rydb.).

Application rates were 0, 1, and 3 pounds active ingredient of atrazine per acre, and 0 and 40 pounds N per acre (120 pounds per acre of 33.5 percent ammonium nitrate) in a factorial design. The treatments were applied at four different dates, the December previous to harvesting, mid-May, mid-June, and early July each year for 3 years. The December and May applications were followed by four monthly harvests and the June and July applications were followed by three monthly harvests. Each month of application was placed in a separate block with three replicates and treatments were repeated on the same plots each year for 3 years. The atrazine, in aqueous solution containing 0.1 percent surfactant (v/v), was applied with a compressed air sprayer at a rate of 20 gallons per acre for each date of application. N was applied in dry form in December and in May. For the June and July applications, N was applied in a water solution at 40 gallons per acre. Plot size was 15 by 50 feet.

Herbage was harvested from one 4.8-square-foot plot on each treatment plot. The herbage samples were ovendried at 70° C. The samples were weighed and ground in a Wiley mill to pass through a 1-mm. screen. N content was determined by standard Kjeldahl method. The samples from all harvests in 1969 and 1970 from the fall application were analyzed for nitrate-N by the xylenol method (*12*). The samples from the first harvest in 1971 for each date of application were analyzed for nitrate-N by the method described by Johnson and Ulrich (*7*). Species frequency was determined in late June each year.

WEATHER

Precipitation was substantially above average during the crop year of 1969 (table 1) with much of the precipitation occurring in June. Precipitation was substantially below average in the crop year of 1970 and slightly below average in 1971. In both years, moisture was below average during the growing season, May through August. A series of storms during late April and early May of 1971 contributed nearly 4 inches of moisture and may have influenced the response of herbage yields to early applications of the 3-pound-per-acre rate of atrazine.

TABLE 1.—*Monthly precipitation (inches) for the crop years (September through August) of 1969, 1970, and 1971, crop year totals, and 33-year mean at Central Plains Experimental Range, Nunn, Colo.*

Year	Month												Crop year total
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
1969	0.40	0.96	0.68	0.21	0.12	0.26	0.24	1.57	2.26	4.64	1.75	1.39	14.48
1970	1.23	2.81	.10	(1)	.05	.05	1.31	1.34	.84	1.14	1.56	.24	10.67
1971	1.48	1.15	.15	.23	.45	.30	.89	2.82	1.67	1.23	.61	.36	11.34
33-year mean 1939–71	1.07	.75	.25	.16	.28	.22	.60	1.10	2.14	2.42	1.83	1.45	12.27

[1] Trace.

RESULTS

Crude Protein

Atrazine Effects

Atrazine significantly ($P > .95$) increased average crude protein content of herbage over the period of study regardless of time of application (table 2). The 1-pound rate of atrazine increased average crude protein content 1.1 to 1.2 percentage points or 13 to 14 percent for the December, May, and June applications. For the July application, the 1-pound rate of atrazine increased crude protein content only 0.5 percentage points or 6 percent.

The 3-pound rate of atrazine was substantially more effective in increasing crude protein content than the 1-pound rate. Atrazine at 3 pounds per acre was more effective when applied in December than in May. Average increases in protein for December and May applications were 3.5 percentage points or 42 percent and 3.2 percentage points or 36 percent, respectively. The 3-pound rate of atrazine also was more effective when applied in June than when applied in July. Average increases in crude protein content were 2.3 percentage points or 28 percent and 1.3 percentage points or 14 percent, respectively.

The greatest increase in crude protein content from December application of both the 1 pound and 3 pounds per acre of atrazine was found in 1971, a drought year. In 1971, the increases in protein were 1.7 percentage points or 19 percent and 4.5 percentage points or 50 percent for the two rates, respectively.

Nitrogen Effects

Throughout the study, the effects of N on crude protein content were statistically independent of the effects of atrazine.

Application of 40 pounds N per acre significantly increased crude protein content of herbage each year regardless of date of application. Overall, the average increases for the four dates of application ranged from 2.2 to 2.5 percentage points or 25 to 33 percent.

The relationship of increases in crude protein content from 40 pounds N per acre to increases from atrazine treatments varied between dates of application. Average increases in crude protein content of herbage due to N remained approximately constant for all dates of application, whereas the increases from the atrazine treatments were progressively smaller from the December application to the July application. For the December application, the average increase in crude protein content from the N treatment was about 36 percent less than the average increase from the 3-pound rate of atrazine; for the May application, 30 percent less; for the June application, 18 percent greater; and for the July application, 107 percent greater.

Combined Atrazine and Nitrogen Effects

The proportional increases in crude protein due to atrazine were about the same with or without the addition of the 40 pounds N and regardless of date of application. However, for all dates of ap-

TABLE 2.—*Percentage crude protein of herbage harvested in 1969, 1970, and 1971 and 3-year averages for 0, 1, and 3 pounds per acre of atrazine with 0 and 40 pounds per acre of nitrogen. Treatments applied in December, May, June, and July each year*

Month of application	Rate of nitrogen applied	Rate of atrazine applied	Year harvested			Average
			1969	1970	1971	
	Pounds per acre	*Pounds per acre*	*Percent*	*Percent*	*Percent*	*Percent*
December	0	0	6.9 d[1]	7.1 d	7.5 e	7.2 e
		1	7.8 c d	7.5 d	9.3 d	8.2 d
		3	10.9a b	9.4 c	12.8 b	11.0 b
	40	0	8.5 c	9.8 b c	11.1 c	9.8 c
		1	9.9 b	10.7 b	12.5 b	11.0 b
		3	11.2a	12.5a	14.2a	12.7a
May	0	0	6.8 c	7.0 d	7.6 e	7.1 e
		1	7.3 c	8.7 c	9.1 d	8.3 d
		3	10.0a	10.4 b	12.1 b c	10.8 b
	40	0	8.5 b	9.9 b c	11.6 c	10.0 c
		1	9.1 b	10.8 b	12.4a b	10.8 b
		3	10.6a	12.2a	13.4a	12.1a
June	0	0	5.9 c	6.5 c	7.4 d	6.6 e
		1	6.0 c	7.6 c	8.6 c	7.4 d
		3	7.9 b	9.1 b	10.8 b	9.3 c
	40	0	7.3 b	9.1 b	11.3 b	9.2 c
		1	9.4a	10.7a	11.8a b	10.6 b
		3	10.1a	10.4a	12.7a	11.1a
July	0	0	6.1 e	7.9 c	7.8 e	7.3 f
		1	7.3 d	8.3 b c	8.7 d e	8.1 e
		3	7.4 c d	9.2 b	9.2 c d	8.6 d
	40	0	8.2 b c	10.6a	10.4 b c	9.7 c
		1	8.5a b	11.3a	10.7 b	10.2 b
		3	9.2a	11.4a	12.4a	11.0a

[1] Column means for the same year of harvest or averages and the same date of application when followed by the same letter are not significantly different at the 5-percent level.

plication, crude protein levels were higher with the addition of N regardless of rate of atrazine applied.

The increased crude protein content of herbage from the atrazine and N combinations applied in December was consistent throughout the summer (fig. 1). The most effective December treatment for increasing crude protein content was the combination of 3 pounds atrazine and 40 pounds N. In June, the December application increased crude protein content an average of 7.5 percentage points or 87 percent, and in September the increase averaged 4.7 percentage points or 80 percent. The combination of 1 pound of atrazine and 40 pounds of N increased crude protein content through the summer about as much as the 3-pound atrazine treatment alone.

Herbage Yields

Atrazine Effects

In 1971, a substantial decrease in herbage yields was found for the 4 pounds of atrazine applied both in December and in May. These decreases were 25 percent and 14 percent, respectively.

These decreases seem related to a series of storms that contributed about 4 inches of precipitation during late April and early May of 1971. Very few plants had begun growth by this time. The consequent high soil moisture level in April and May may have increased effectiveness of the 3-pound rate of atrazine already present from the December application and that applied a short time after the storms in May. The increased effectiveness of the high rate of atrazine substantially reduced growth of the native plants during May and June. This deleterious effect of the 3-pound rate of atrazine on yields disappeared by the July harvest date in 1971.

When applied in early July, both rates of atrazine decreased average herbage yields. These decreases were small—9 percent and 12 percent for the 1- and 3-pound rates of atrazine, respectively—but statistically significant ($P > .95$).

Nitrogen Effects

The 40 pounds N per acre substantially increased average herbage yields over the period of study regardless of date of application. However, the N treatment applied in July had no effect on herbage yields in 1970 or 1971. The average increase in herbage yields from the N treatment was greatest for the December date of application—40 percent. The average increase in herbage yield from the N treatment became progressively less with progressively later dates of application—33 percent increase for the May date of application, 23 percent for the June application, and 15 percent for the July application.

Combined Atrazine and Nitrogen Effects

The 1-pound rate of atrazine increased herbage yields slightly whether alone or combined with N when applied in either December or in May (table 3). The 3-pound atrazine rate had essentially no effect on overall yields, with or without added N, for either December or May applications. Average herbage yields were increased by the addition of 40 pounds N to all atrazine treatments. For both December and May application, the most effective treatment for increasing average herbage yields was the combination of 1 pound atrazine and 40 pounds N.

When applied in June, both rates of atrazine increased average herbage yields without added N. With added N, neither rate of atrazine increased yields. When applied in July, neither rate of atrazine affected herbage yields without added N. With added N, both rates of atrazine decreased yields. This was a distinct negative interaction of atrazine and N on average herbage yield.

When applied in June or July, 40 pounds of N alone was the most effective treatment for increasing average herbage yields.

For the December applied treatments, the combination of 1 pound atrazine and 40 pounds N was the most effective treatment for increasing average herbage yields during the harvest period of June through September (fig. 2). The treatment increased yields 68 percent in June and 43 percent

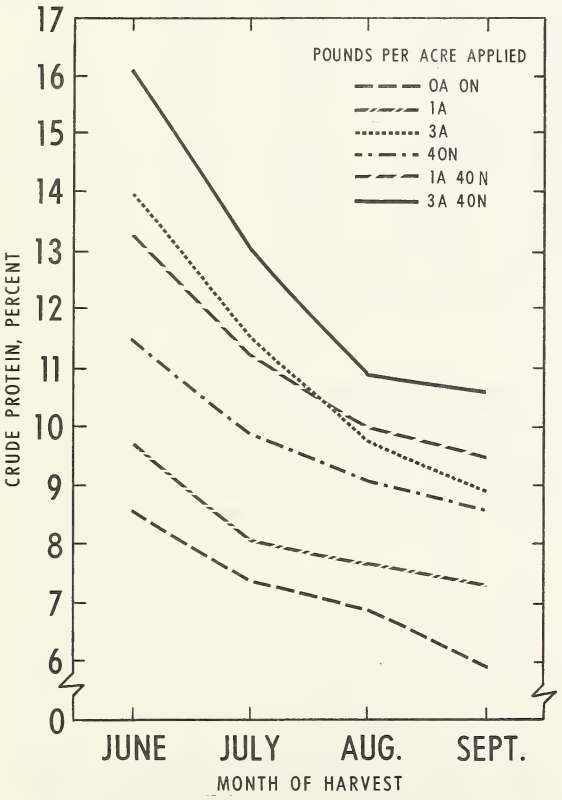

FIGURE 1.—Average crude protein content (percent) of range herbage showing effects of December application of atrazine (A) and nitrogen (N) combination treatments and months of harvest, 1969–71.

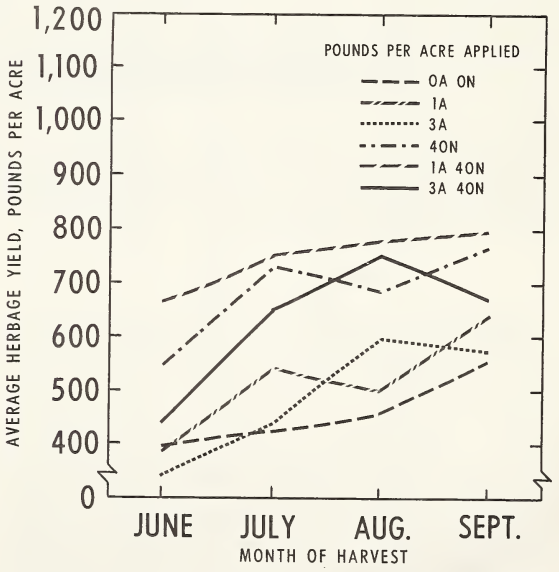

FIGURE 2.—Average herbage yields (pounds per acre) showing effects of December applications of atrazine (A) and nitrogen (N) combination treatments and months of harvest, 1969–71.

TABLE 3.—*Dry matter yield of herbage (pounds per acre) harvested in 1969, 1970, and 1971 and 3-year averages for 0, 1, and 3 pounds per acre of atrazine and 0 and 40 pounds per acre of nitrogen. Treatments applied in December, May, June, and July each year*

Month of application	Rate of nitrogen applied	Rate of atrazine applied	Year harvested			Average
			1969	1970	1971	
			Pounds per acre			
December	0	0	[1] 704 b	364 b	318 b	463 c
		1	784 b	460a b	312 b	519 c
		3	698 b	512a b	256 b	489 c
	40	0	1,030a	582a	438a	684a b
		1	1,184a	608a	488a	749a
		3	998a	584a	308 b	631 b
May	0	0	700 b	430 b	344a b	492 b
		1	754 b	522 b	392a	556 b
		3	822a b	476 b	282 b	527 b
	40	0	886a b	714a	404a	668a
		1	1,012a	724a	444a	728a
		3	972a	746a	364a b	694a
June	0	0	1,002 b	520 b	366 b	630 c
		1	1,076a b	622a b	502a	734a b c
		3	1,142a b	612a b	418a b	724 b c
	40	0	1,374a	834a	512a	906a
		1	1,254a b	584a b	522a	787a b c
		3	1,282a b	840a	506a	877a b
July	0	0	1,016 b	620a b	432a	689 b
		1	1,052 b	582a b	422a	685 b
		3	1,016 b	536a b	466a	673 b
	40	0	1,434a	772a	494a	900a
		1	1,120 b	624a b	488a	745 b
		3	1,206a b	512 b	432a	717 b

[1] Column means for the same year of harvest or averages and the same date of application when followed by the same letter are not significantly different at the 5-percent level.

in September. For the December application, 40 pounds N alone or with 3 pounds atrazine were the next most effective treatments.

Protein Yields

The effects of the atrazine and N, separately and in combination, on yield of protein tended to follow the effects of these treatments on herbage yields but with some modification due to the substantial effect of the 3-pound rate of atrazine on increasing protein content of herbage. The most effective treatments for increasing total protein yields were either 1 pound or 3 pounds of atrazine in combination with 40 pounds of N applied in December, or the combination of 3 pounds of atrazine and 40 pounds of N applied in May or June (table 4). The first two combinations increased average yield of protein 142 to 148 percent. The last combination treatment increased yield of protein 131 to 140 percent. When applied in early July, the most effective treatment was the application of 40 pounds of N alone. When applied in July, N only increased average yield of protein 74 percent.

When applied in December or in May, there was a slight negative interaction between the two rates of atrazine and 40 pounds of N on protein yields. For example, without added N, the 1-pound rate of atrazine applied in December increased yield of protein an average of 10 pounds per acre and the 3-pound rate of atrazine increased yield of protein 21 pounds per acre (table 4). When combined with N, the 1-pound rate of atrazine applied in December increased protein yield 15 pounds per acre, but the 3-pound rate of atrazine increased protein

yield only 13 pounds per acre over the N-only treatment.

The negative interaction between the two rates of atrazine and N on protein yield was substantial for both the June and July dates of application. For the June application, the 1-pound rate of atrazine alone increased average yield of protein 12 pounds per acre, and the 3-pound rate of atrazine alone increased average yield of protein 25 pounds per acre. When N was added, the 1-pound rate of atrazine had no effect on average yield of protein, and the 3-pound rate of atrazine increased average yield of protein only 14 pounds per acre.

It was apparent that both rates of atrazine tended to be equally effective with or without added N when applied in December or in May. However, when applied in June or July, added N reduced the stimulatory effects of atrazine on protein yield.

Nitrate-N

The herbage from all monthly harvests in both 1969 and 1970 for the December applications of atrazine and N and that of the first monthly harvest in 1971 for each month of application were analyzed for nitrate-N content (table 5). In the first growing season following the December application, neither atrazine nor N influenced nitrate-N content of herbage. During the second

TABLE 4.—*Protein yield (pounds per acre) (herbage yield multiplied by percent crude protein) harvested in 1969, 1970, and 1971 and 3 year averages for 0, 1, and 3 pounds per acre of atrazine and 0 and 40 pounds per acre of nitrogen. Treatments applied in December, May, June, and July each year*

Month of application	Rate of nitrogen applied	Rate of atrazine applied	Year harvested			Average
			1969	1970	1971	
			Pounds per acre			
December	0	0	49	26	24	33
		1	61	34	29	43
		3	76	48	33	54
	40	0	88	57	49	67
		1	117	65	61	82
		3	112	73	44	80
May	0	0	48	30	26	35
		1	55	45	36	46
		3	82	50	34	57
	40	0	75	71	47	67
		1	92	78	55	79
		3	103	91	49	84
June	0	0	59	34	27	42
		1	65	47	43	54
		3	90	56	45	67
	40	0	100	76	58	83
		1	118	62	62	83
		3	130	87	64	97
July	0	0	62	49	34	50
		1	77	48	37	56
		3	75	49	43	58
	40	0	118	82	51	87
		1	95	70	52	76
		3	111	58	54	79

growing season and following a second December application, the 40 pounds of N increased nitrate-N content of herbage slightly.

The third annual application of 3 pounds af atrazine per acre, from both the December and May dates of application, tripled the nitrate-N content of herbage harvested in June 1971. However, the third annual application of atrazine applied in either June or early July had no effect on nitrate-N content of herbage harvested in late July. The herbage from both the May application of 40 pounds of N harvested in June and the June application harvested in July showed an approximate doubling of nitrate-N content. Herbage harvested in late July 1971 from the early July application of N showed an eightfold increase in nitrate-N content.

Species Composition

Atrazine substantially reduced frequency of occurrence of one perennial species (scarlet globemallow) and four annual species during the study (table 6). Two of the annual species, sixweeks fescue and slim-leaf goosefoot (*Chenopodium leptophyllum* Nutt.), are probably undesirable, and one, Russian thistle (*Salsola kali tenuifolia* Tausch), may be desirable forage, particularly during drought. Scarlet globemallow is a desirable perennial forb. However, Redowski stickseed (*Lappula redowski* (*Hornem.*) *Greene*) is inconsequential as forage despite its abundance.

The abundance of both slimleaf goosefoot and Russian thistle were substantially increased by application of N. The increase from N occurred only

TABLE 5.—*Nitrate-N content of herbage harvested in 1969, 1970, and 1971 for 0, 1, and 3 pounds per acre of atrazine and 0 and 40 pounds per acre of nitrogen. Treatments repeated 3 years on the same plots*

Date of application	Date of harvest	Rate of nitrogen applied	Nitrate-N content of herbage for following applied rates (lb./acre) of atrazine			Average
			0	1	3	
		Pounds per acre	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
December 1968	[1]1969		[2]53a	51a	54a	52
December 1969	[1]1970	0	51	50	53	51 b
		40	62	56	59	59a
Average			54a	52a	56a	
December 1970	June 1971	0	50 b	50 b	210a	105a
		40	80 b	100 b	180a	120a
Average			65 b	75 b	195a	
May 1971	June 1971	0	40 b	70 b	130a	80 b
		40	110 b	130 b	290a	175a
Average			75 b	100 b	210a	
June 1971	July 1971	0	70a	90a	110a	90 b
		40	180a	200a	180a	190a
Average			125a	145a	145a	
July 1971	July 1971	0	90a	120a	120a	110b
		40	930a	880a	930a	915a
Average			510a	500a	525a	

[1] Plots were harvested in June, July, August, and September. Data are means over these 4 harvests.

[2] Row averages comparing rates of atrazine or column averages comparing rates of nitrogen for individual dates of application when followed by the same letter are not significantly different at the 5-percent level.

where atrazine was absent. Hyder and Bement (*5*) also found substantial increases in these two species following N fertilization of abandoned cropland.

TABLE 6.—*Average frequency of occurrence of selected species for 1969–71 showing overall effects of atrazine and nitrogen treatments* [1]

Species	Rate of atrazine applied (lb./acre)			Rate of nitrogen applied (lb./acre)
	Mean frequency	*Percentage change*		
Scarlet globemallow	31	[2]—5	—41	
Sixweeks fescue	30	—87	—95	
Slimleaf goosefoot	11	—97	—99	+185
Redowski stickseed	7	—88	—97	
Russian thistle	7	—86	—99	+273

[1] Includes only species of 5-percent frequency or more that were significantly ($P>0.95$) influenced by treatments.

[2] The 1-pound rate of atrazine did not significantly affect frequency of this species.

DISCUSSION AND CONCLUSIONS

On semiarid rangelands, the most valuable treatments were probably those that increased protein yields (or herbage quality) without depressing herbage yields (or quantity) or increased both. A previous study with atrazine showed consistent reductions in dry matter yields following treatment (*3*). In this study, we found decreased yields from application of atrazine only at the high rate (3 pounds per acre), only in one year (1971), and only from two out of the four dates of application studied (December and May). Even this risk of decreased yields is probably too great. In this light, the most effective treatment found in this study for increasing protein yield of shortgrass range and for application in either December or in May was the combination of 1 pound of atrazine and 40 pounds of N per acre. This treatment was about equally effective for either date of application. For application in June, the most effective treatment with low risk of reduced yields was the combination of 3 pounds of atrazine and 40 pounds of N per acre. For application in early July, the most effective treatment was 40 pounds N per acre alone.

From the viewpoint of economics in the United States, the N treatment alone was probably the most profitable regardless of date of application. This is due to the very low price of nitrogen fertilizer as compared to the price of atrazine. However, in other areas of the world, N is considerably more expensive. In those areas, atrazine with its low shipping weight already may be competitive with N fertilizer for increasing protein yield of herbage. Of course, atrazine cannot compete with N for increasing herbage yields. The herbicidal effect of atrazine on decreasing undesirable annuals would be a bonus.

In this study, repeated applications of both 40 pounds of N as ammonium nitrate and 3 pounds atrazine increased nitrate-N content of herbage. The increases from atrazine applications were much less than those from ammonium nitrate. The greatest increases in nitrate-N from repeated applications of ammonium nitrate were found where the N was applied in early July and harvested in late July. However, the highest levels of nitrate-N in forage found in this study did not reach levels considered toxic to livestock (2,000 parts per million) (*1*).

The species controlled by atrazine were mostly undesirable or inconsequential forage. The overall herbicidal effect of atrazine was improvement of forage composition.

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